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COINTEGRATED VECTOR AUTOREGRESSION METHODS: AN APPLICATION TO NON-NORMALLY BEHAVING DATA ON SELECTED U.S. SUGAR-RELATED MARKETS

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ABSTRACT: The methods of the cointegrated vector autoregression/error correction (VAR/VEC) model are applied to monthly U.S. markets for sugar and for sugar-using markets for confectionary, soft drink, and bakery products. Primarily a methods paper, Johansen and Juselius' methods are applied, with a special focus on addressing well-known issues that preclude statistically normal behavior, and that confront the modelled sugar-based data. In so doing, we illustrate the effectiveness and the benefits of modelling this sugar-related set of markets as a cointegrated system. Perhaps for the first time, cointegrated VEC model results are used to estimate crucial policy-relevant market parameters that drive the markets, as well as to illuminate the dynamic nature of the relationships linking these sugar-based markets.

Key words: Cointegration, sugar-based U.S. markets, vector autoregression, vector error correction models.

Cointegrated Vector Autoregression Methods: An Application to Non- Normally Behaving Data on Selected U.S. Sugar-Related Markets

Introduction

Little or no literature has been located where the methods of the cointegrated vector autoregression (VAR) model have been applied to estimate the relationships among the U.S. markets for raw sugar (hereinafter the "upstream market"), and the sugar-using, value-added markets downstream for confectionary, soft drink, and bakery products (hereinafter, the "downstream" and/or "sugar-using markets"). The primary purpose of this study is a methods-based one: to provide an appropriate econometric application of the methods of the cointegrated VAR model of Johansen and Juselius (1990, 1992) to the U.S. sugar market and several downstream U.S. sugar-using product markets. The overall hypothesis to be tested is whether, as theory would suggest, U.S. prices and quantities of sugar, and sugar-using confectionary, soft drink, and bakery products form a cointegrated econometric system. In so doing, and of equal importance as a second purpose, is to estimate parameters that drive these markets and illuminate how the markets dynamically interact through sound statistical estimation of the long run cointegration space. Such statistical estimates and dynamic relationships include (among others) price elasticities of sugar demand, cross-price relationships between raw sugar and downstream sugar-using value-added products, and cross-price relationships among confectionary, bakery, and soft drink prices downstream. The second purpose is of great current interest, given that the United States has either concluded, or commenced negotiations with, a number of major sugar exporters (e.g. Australia, Thailand) that would like increased access to the U.S. market. U.S. sugar producers naturally oppose any increased foreign access to the U.S. sugar market, while U.S. sugar-using agents in the confectionary, soft drink, and bakery industries welcome increased sugar imports (see U.S.-Thailand Free Trade Agreement Business Coalition, 2004). Nonetheless, the purpose is to properly apply these cointegrated vector error correction (hereinafter VEC) modelling methods to such U.S. sugar-related markets, and to provide first-time econometric estimates of sugar-related market parameters upon which future research could expand and improve.

Since the United States appropriately falls under a "large country" classification for many commodity-based trade investigations, hearings often attract both U.S. producers of a commodity (here sugar) as well as commodity users (here, U.S. confectioners, bakers, etc.) (see U.S.-Thailand Free Trade Agreement Business Coalition, 2004). Both sides typically argue, often fiercely, opposing positions on such issues as potentially expandable import access into the U.S. sugar market, since imported and domestic raw sugar are generally highly substitutable in the U.S. market. A cointegrated VEC model of these upstream and downstream sugar-related product markets provides a rich set of parameter estimates and other econometric results that illuminate the long run relationships in the cointegration space that drive and interrelate these sugar-related markets. In turn, these econometric estimates and results that illuminate the long run and dynamic properties of the market forces are useful to agribusiness agents, sugar growers, sugar product manufacturers and consumers, and sugar policy makers. For instance certain price elasticities can show how demand and/or supply for sugar are affected by a change in the price of sugar, and/or in a sugar-using product on a cross-price basis. Such long run results can also illuminate how sugar-based product prices are interrelated, and how they react to a change in raw sugar supply from a rise in imports or production. Capturing such relationships among U.S. sugar-based markets constitutes a tailor-fit application for methods of the cointegrated VAR model developed and summarized by Johansen and Juselius (1990, 1992) and Juselius (2004).

The remainder of this paper is comprised of seven sections. The first presents a discussion on time series econometrics and the cointegrated VEC as a way of empirically modelling monthly U.S. sugar and sugar-based markets. The five modelled markets are presented, along with the data and data sources.

A second data analysis section examines the trends and issues of statistically non-normal behavior confronting the chosen data series. The third section provides specification of the system as a traditional levels-based VAR model. Following Juselius (2004, chapter 4), effort is expended on achieving an adequately specified levels VAR model and its algebraic equivalent, an unrestricted VEC model, before cointegration is tested for, before rank is imposed on the cointegrated space, and prior to the conduction of theory-based statistical hypothesis tests on the emergent cointegrating relation(s). This section provides a rigorous analysis of the results from a battery of diagnostic mis-specification tests suggested in Johansen and Juselius (1990, 1992) and Juselius (2004, pp. 72-82). Fourth, Johansen and Juselius' (1990, 1992) well-known trace test and other analysis are used to determine the rank of the cointegration space and the number of long run cointegrating relationships. The cointegration space is then restricted for this reduced-rank. A discussion of Johansen and Juselius' (1990, 1992) application of the Frisch-Waugh theorem to render a maximum likelihood estimator of the reduced rank cointegration space is also provided. Fifth, Johansen and Juselius' well-known hypothesis test procedures are applied to the rank-restricted cointegration space to reveal the nature of the long run relationships tying together the upstream and downstream sugar-based markets. A sixth section provides an economic interpretation of the cointegrating relations that are fully restricted for rank and for statistically-supported restrictions that emerged from the hypothesis tests. And finally, a summary and conclusions follow.

Time Series Econometric Considerations, Modelled Markets, and Data Sources

Since Engle and Granger's (1987) paper, it is well-known that economic time series often fail to meet the conditions of weak stationarity and ergodicity summarized by Granger and Newbold (1986, pp. 1-5). Nonetheless, it is also well-known that while data series are often individually nonstationary, they can form vectors with linear combinations which are stationary, such that the vector of interrelated series are "cointegrated" and move together or in tandem as an error-correcting system (Johansen 1990, 1992; Juselius 2004). These well-known econometric concepts are summarized, and not detailed, here: readers wanting more detail are referred to the just-cited sources. As will be evidentially demonstrated later, readers should note that all modelled endogenous variables are nonstationary: integrated of order-1 or I(1), with the first differences being stationary, that is integrated of order-zero or I(0).[1]

All data are seasonally unadjusted. A rigorous search of monthly data resources on U.S. sugar-based variables provided the six variables related for the January 1992–March 2004 period. Unfortunately, data were not available for periods prior to January 1992, and due to the number of endogenous variables and deterministic variables to be added from later analysis, there are potential problems with small samples. The following are the six variables (denoted throughout by the parenthetical labels) which we propose as an unrestricted VAR and ultimately as a cointegrated VAR model:

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[1] Juselius (2004, pp. 221-223) recommends that the stationarity tests on any single time series should be conducted with a chi-square-distributed likelihood ratio statistic within the concept of a modelled system that is restricted for rank. She contends that an individual series' stationarity or nonstationarity is not independent of rank of the error-correction term's Π matrix (Juselius 2004, pp. 221-223). Consequently, Juselius cautions against using univariate tests such as the Dickey-Fuller tests. Juselius (2004, pp. 221-223) suggests that one take a system suspected as cointegrated; obtain an adequately specified levels VAR and equivalent unrestricted VEC; and then test for variable stationarity with a chi-square test value for each variable within a system. If evidence suggests that all of the endogenous variables are indeed stationary, then one re-specifies as a levels VAR. But we must present these stationarity test results later after achievement of an adequately specified levels VAR and unrestricted VEC.

1. The market-clearing quantity of available sugar in the United States (QSUGAR), which includes all shipments, ending stocks and imports of sugar in raw sugar equivalents, published by the United States Department of Agriculture, Economic Research Service (USDA, ERS 2004).

2. The market-clearing U.S. price of raw sugar (PSUGAR) published by the USDA, ERS (2004).

3. The producer price index ("PPI") or price of U.S. chocolate-based confectionary products (PCHOC), PPI series number PCU311320311320, from the U.S. Department of Labor, Bureau of Labor Statistics (Labor, BLS 2004).

4. The price of non-chocolate confectionary products (PNOCHOC), PPI series number PCU3113403113401 from Labor, BLS (2004).

5. The price of U.S. soft drink products (PSOFT), PPI series number PCU312111312111, from Labor, BLS (2004).

6. The U.S. price of commercial bakery products (PBAKERY), PPI series number PCU311812311812, from Labor, BLS (2004).

Unfortunately, quantity and stock data are not available on a monthly or quarterly basis for the chocolate-based confectionary, non-chocolate confectionary, soft drink, and commercial bakery product markets. PSOFT contains products which are intensive users of both sugar and high fructose corn syrup (HFCS), which some contend are two separate sweetener product markets that do not compete for sugar. And so PSOFT may contain mutually offsetting trends and is likely not an ideal price proxy for sugar-based soft drinks price, although no better price was located. Consequently, PSOFT, which does include sugar-based products, was included to avoid potentially serious mis-specification error from a complete omission of the soft drink industry, a consumer of both sugar and HFCS.

Analysis of the Sugar-Based Time Series Data

Following Juselius (2004), Bessler (1984), and Bessler and Akleman (1998), all data are in natural logarithms and differences are of the logged levels data. Figures 1 through 6 provide the plotted (logged) levels of the modelled data in the upper panels, and the data in first-differences of logged levels in the lower panels. A weakly stationary data series has a constant and finite mean and variance, time-independent observations, and generates regression coefficient estimates that are time-invariant and not subject to statistical structural change (Juselius 2004, chapters 3 and 4). Weakly stationary data typically behave in frequently repeating and mean-reversive cycles. A number of data issues clearly arise that preclude weakly stationary behavior necessary for valid time-series regressions.

QSUGAR or the market-clearing sugar quantity in figure 1 is clearly saddled with seasonal effects which likely mask an upward trend that is only minimally evident from the plotted levels. Figure 1 suggests the potential need for centered seasonal dummy variables and for a linear trend.

The price of raw sugar (PRAW) reflects several serious issues in figure 2 that involve normal behavior. It is well-known that the U.S. sugar market is highly regulated, and has been so-regulated for many decades. However, the following four major changes in U.S. sugar policy clearly destabilized the

U.S. sugar market, as particularly evident from figure 2's plotted levels and differences in PRAW during sample period’s latter half:[2]

- two separate periods of domestic marketing allotments during October 1990– September 1996 and October 2000– present. These allotment programs were designed to restrict U.S. raw sugar supply, and presumably augmented U.S. raw sugar price (taken as two policy changes).

- two separate but consecutive budget years of payment-in-kind (PIK) during October, 2001 through September, 2003 when farmers were “paid” program benefits in-kind with raw sugar which they presumably sold on the open market. This PIK program tended to increase marketed QSUGAR quantities and presumably dampened PRAW on the open market (taken as one policy change).

- and the May 2002 implementation of a U.S. government import quota swap program which restricted imported raw sugar supplies in response to increased domestic production. This program tended to augment PRAW through restricted raw sugar supplies in the U.S. market.

PRAW differences also suggest that there have been a number of observation-specific non-normal “outlier” effects throughout much of the sample. Specification considerations include a permanent shift dummy variable for the post-1999:07 part of the sample; seasonal dummy variables given the agricultural nature of PRAW; appropriately specified observation-specific dummy variables to account for any influences of extraordinary events and to account for a variance that is time-variant (ARCH effects); and a possible trend.

The price of chocolate-based confectionary products (PCHOC) in figure 3 has a number of serious behavioral issues inconsistent with weak stationarity. There is persistent trending, little or no cycling of levels data, and hence little or no mean-reversive behavior. There is also a dramatic change in slope starting in the early-2000's, which appears to be a permanent shift with approximate resumption of the pre-shift slope. This change in slope is likely caused by two events: an extraordinary and sustained run-up in cocoa prices in 2001 due to the Côte d’Ivoire civil war, and an extraordinary late-2002 rise in other non-cocoa confectionary input costs.[3] Specification considerations include a permanent-shift dummy defined for the 1999:07-2004:03 subsample, two permanent-shift dummy variables to account for the 2001 rise in cocoa price and the late-2002 rise in the prices of non-cocoa confectionary inputs, a series of appropriately specified observation-specific dummy variables to account for intermittent outliers and ARCH effects evident throughout the sample, and a linear trend.

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[2] Price stability shown in figure 2 was attributed to U.S. sugar policy changes by the sugar market analyst with the Agriculture and Forest Products Division, Office of Industries, USITC, in emails received by one of the authors on Aug. 18 and 20, 2004.

[3] These two events were offered as possible explanation for this permanent shift in PCHOC slope after early-2000 from information compiled, in consultation with U.S. Department of Labor analysts, by the sugar market analyst with the Agriculture and Forest Products Division, Office of Industries, USITC, in emails received by one of the authors on Aug. 18 and 20, 2004.

Figure 1
Plots of logged levels and differences: QSUGAR

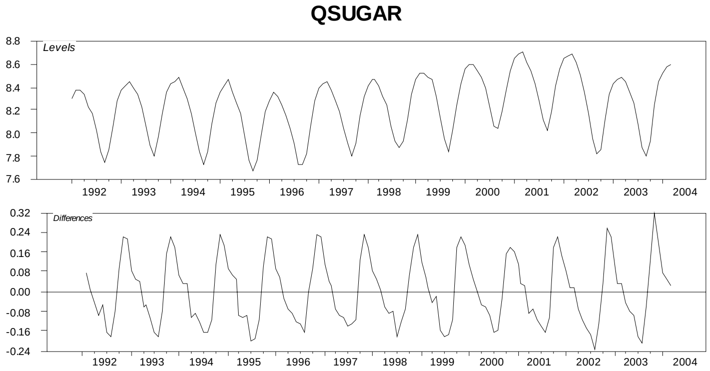


Figure 2
Plots of logged levels and differences: PRAW

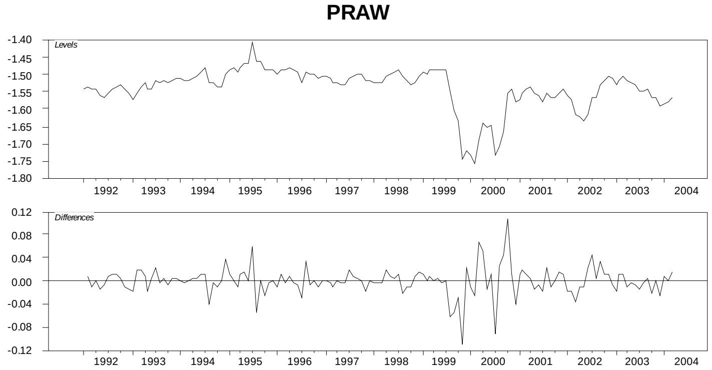
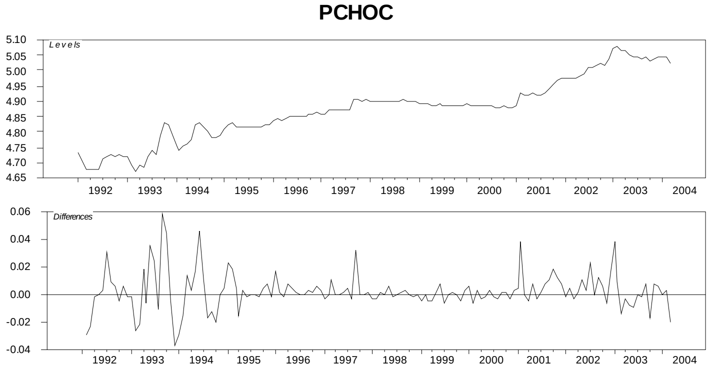


Figure 3
Plots of logged levels and differences: PCHOC



The price of non-chocolate confectionary products (PNOCHOC) in figure 4 also displays behavioral issues inconsistent with weak stationarity. There is little or no cycling behavior of the data or mean-reversive behavior. There is a clear permanent shift in the plotted levels series with resumption of the pre-shift slope for the period of late-2002 through the sample period's end. This permanent shift was likely elicited by a sustained, late-2002 rise in costs of non-cocoa confectionary production materials.[4] Specification considerations include a linear trend; a permanent shift dummy variable defined over the 2002:12-2004:03 subsample; and a number of appropriately specified observation-specific dummy variables to account for effects of extraordinary events and ARCH effects throughout the sample.

Plots and differences of the soft drink and commercial bakery price series are in figures 5 and 6. Little or no cycling or mean-reversive behavior is evident. Specification considerations include a linear trend, and a number of various appropriately specified observation-specific dummy variables to account for effects of extraordinary outlier events.

The Statistical Model: The Unrestricted VAR and VEC Equivalent[5]

Throughout, a number of terms are used: (1) the *unrestricted levels* VAR denotes a VAR model in logged levels; (2) an *unrestricted VEC* denotes the algebraic equivalent of the unrestricted levels VAR in error correction form, where the levels component (cointegration space) is not yet restricted for reduced rank or for statistically supported restrictions; (3) the *cointegrated VEC* is the unrestricted VEC equivalent of the logged levels VAR just mentioned where the cointegration space has been restricted for reduced rank; and (4) the *fully restricted cointegrated VEC* is the unrestricted VEC after the cointegration space's restriction for reduced rank and for the statistically supported restrictions on cointegration space coefficients that emerge from the hypothesis tests. As well, "p" denotes the number of endogenous variables (i.e., six); "p1" denotes the number of variables in the cointegration space (six endogenous and various deterministic variables introduced later); and "r" represents the rank of the cointegration space (and the number of cointegrating relations).

The goal of this subsection is to specify and estimate an adequately specified unrestricted levels VAR of the system and its algebraic equivalent, an unrestricted VEC (Juselius 2004, chapter 5). Adequate specification implies estimated residual behavior which approximates well-known assumptions of multivariate normality.[6] The first step is to specify and estimate an unrestricted VAR model in levels and its unrestricted VEC equivalent (defined below) with the data (in figures 1-6) that initially reflect statistically non-normal behavior.

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[4] That the late-2002 rise in the costs of non-cocoa confectionary production materials is a reason for the post-2002 permanent shift in PNOCHOC levels series was based on information compiled, in consultation with U.S. Department of Labor analysts, by the sugar market analyst with the Agriculture and Forest Products Division, Office of Industries, USITC, in emails received the author on Aug. 18 and 20, 2004.

[5] This section draws heavily on the work of Johansen and Juselius (1990, 1992) and Juselius (2004).

[6] The six series should each be weakly stationary: have a constant and finite mean and variance, and observed values that are not time-dependent (Juselius 2004, p. 42). The vector of the unrestricted VEC should be multivariate normal with constant vectors of finite means and of a constant variances. The VAR model should be linear in the parameters; have constant parameters; and have normally distributed error terms (Juselius 2004, p. 49). That is, the estimated VAR residuals or the difference between the actual realization and the series mean should be approximately "white noise" and be normally, identically, and independently distributed with a constant and zero mean and a finite constant variance (Juselius 2004, p. 50).

Figure 4
Plots of logged levels and differences: PNOCHOC

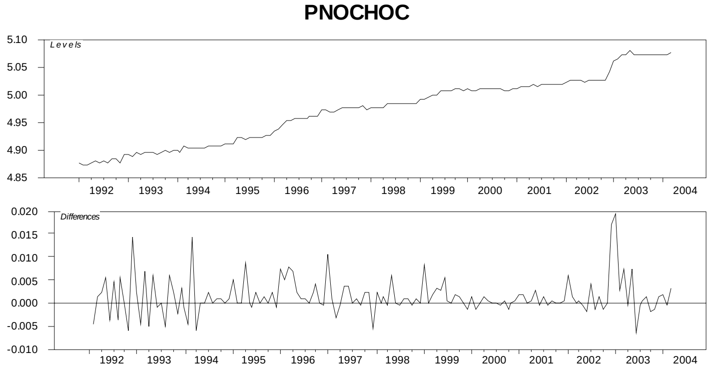


Figure 5
Plots of logged levels and differences: PSOFT

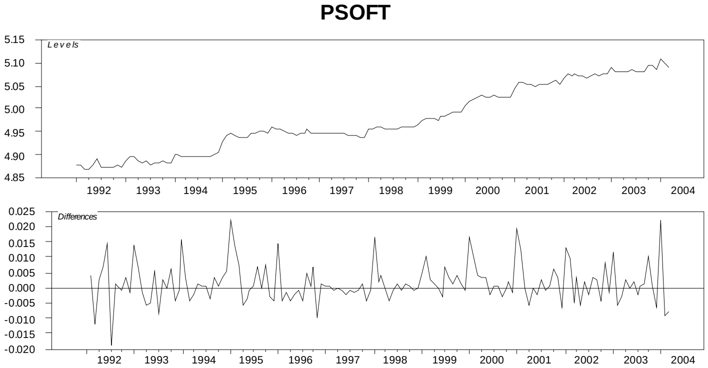
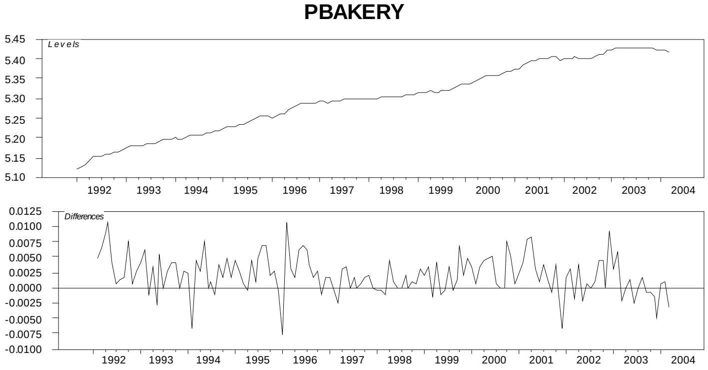


Figure 6
Plots of logged levels and differences: PBAKERY



The levels VAR and unrestricted VEC of the sugar-based market system

Bessler (1984) notes that a VAR model posits each endogenous variable as a function of k lags of itself and of each of the remaining endogenous variables in the system. The above six variables render the following unrestricted and six-equation VAR model in logged levels:

(1) X(t) = a(1,2)*QSUGAR(t-1) + . . .+ a(1,k)*QSUGAR(t-k) +
a(2,1)*PRAW(t-1)+ . . .+a(2,k)*PRAW(t-k) +
a(3,1)*PCHOC(t-1) + ...+a(3,k)*PCHOC(t-k) +
a(4,1)*PNOCHOC(t-1)+ . . .+a(4,k)*PNOCHOC(t-k) +
a(5,1)*PSOFT(t-1)+ . . . . . +a(5,k)*PSOFT(t-k) +
a(6,1)*PBAKERY(t-1)+ . . .+a(6,k)*PBAKERY(t-k) +
a(c)*CONSTANT + $\epsilon(t)$

The asterisk denotes the multiplication operator throughout. The $\epsilon(t)$ is distributed as white noise. X(t)= QSUGAR(t), PRAW(t), PCHOC(t), PNOCHOC(t), PSOFT(t), and PBAKERY(t). The a-coefficients are ordinary least squares (OLS) estimates with the first parenthetical digit denoting the six endogenous variables as ordered above, and with the second denoting lags 1, 2, . . .,k. The a(c) is the coefficient on the intercept. The parenthetical terms on the endogenous variables refer to the lag, with t referring to the current period-t value and t-k referring to the kth lag. Equation 1 also includes 11 monthly centered seasonal variables not shown notationally.

As suggested by Juselius (2004), the lag structure was chosen based on a likelihood ratio test procedure, chosen here as Tiao and Box's (1978) procedure. Results suggested a two-order lag structure (k=2), and throughout, the unrestricted VAR model is denoted as the VAR(2) model. Given the 1992:01-2004:03 data sample located, and the two-order lag, the estimation period for this study is 1992:03 through 2004:03.

Johansen and Juselius (1990) and Juselius (2004, p. 66) demonstrated that the above VAR(2) model in equation 1 is now re-written more compactly as the unrestricted VEC model of equation 2:

(2) $x(t) = \Gamma(1) * \Delta x(t-1) + \Pi * x(t-1) + \Phi * D(t) + \epsilon(t)$

The x(t) and x(t-1) are p by 1 (hereinafter denoted p x 1) vectors of the above six sugar-related variables in current and lagged levels, $\Gamma(1)$ is a p x p matrix of short run regression coefficients on the lagged variables, and Π is a (p x p) error correction term to account for the six endogenous variables. The $\Phi*D(t)$ is a set of deterministic variables: 11 seasonals and a host of other trend and dummy variables which will be added to address the data issues identified above and as further analysis unfolds. The rank-unrestricted Π or error correction term is decomposed as follows:

(3) $\Pi = \alpha*\beta'$ where α is a p x r matrix of adjustment speed coefficients and β is a p x r vector of error-correction coefficients

The $\Pi = \alpha*\beta'$ term is interchangeably denoted as the levels-based long run component, error correction term, or cointegration space of the model. The $[\Delta x*(t-1), \Phi*D(t)]$ is collectively considered the short run/deterministic model component.

The data analysis above suggested a number of considerations for specifying the long run and short run/deterministic components in equation 2. Inclusion of a linear trend (TREND) and three permanent shift dummies (presented below) were considered for the long run cointegration space component. These same variables in differenced form as well as a set of 11 centered seasonal variables were considered for the model's short run/deterministic component. Analysis below will also lead to consideration, where appropriate, of various and appropriately specified outlier dummy variables in the short run/deterministic component.

The data analysis gave rise to the definition of three permanent shift dummies:

- a DS9907 shift dummy was defined as unity for 1999:07 -2004:03 (and zero otherwise) to account for the four above-cited U.S. sugar policy changes.

- a DS0101 shift dummy variable was defined as unity for the 2001:01-2004:03 period (and zero otherwise) to account for the apparent shift in PCHOC trends from a 2001 upward surge in cocoa price arising from the Cote Ivoire civil war and a late-2002 rise in prices of other confectionary materials prices.[7]

- a DS0212 shift dummy was defined for 2002:12-2004:03 (zero otherwise) to account for a permanent shift in PNOCHOC from a late-2002 rise in prices of non-cocoa of confectionary production inputs.[8]

The initial estimation starting point for the unrestricted VEC model was equation 2 with only the seasonal variables included in the short run/deterministic component of the model. A well-specified unrestricted VEC was achieved in a series of sequential estimations. These estimations added a linear trend, permanent shift dummies and outlier dummy variables, one variable for each estimation, whereby the added variable was retained if it generated a significant t-value and/or if a battery of specification diagnostic test values moved in favorable patterns or directions indicative of improved specification. Following Juselius' (2004, chapters 4, 7, and 9) recommendations, this array of diagnostics includes: (a) trace correlation as an overall goodness of fit indicator, (b) likelihood ratio test of autocorrelation for the system, (c) univariate Doornik-Hansen tests for normality, (d) indicators for skewness and kurtosis, and (e) univariate tests for ARCH effects (heteroscedasticity). The successive estimations were stopped when the series of diagnostic values stabilized and failed to further improve with inclusions of additional dummy variables. After achievement of an adequately specified unrestricted VEC, a test for parameter constancy was performed to discern if there were problems with time-variance of estimated parameters (also known as "statistical structural change").

The sequential estimations were implemented in two basic sets. The first set focused on including, one by one, the following in both the levels-based long run component ($\Pi^*X(t-1)$) and in differenced form in the short run/deterministic component of equation 2 in order to test if the initially obvious data effects from trending, sugar policy changes, and confectionary market shocks were important: DS9907, DS0101, DS0212, and TREND. In each of four sequential estimations, another of these four variables was included in the long run and short run/deterministic components, if it generated a statistically significant coefficient and/or if the array of diagnostic values moved favorably to suggest

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[7] The source of this information was compiled by the U.S. International Trade Commission industry analyst responsible for monitoring markets for sugar and sugar-containing products, and in consultation with U.S. Department of Labor analysts. Two emails were received from the USITC analyst on Aug. 18 and 19, 2004.

[8] The source of this information was compiled by the U.S. International Trade Commission industry analyst responsible for monitoring markets for sugar and sugar-containing products, and in consultation with U.S. Department of Labor analysts. Two emails were received from the USITC analyst on Aug. 18 and 19, 2004. Note that DS0101 also includes the event for which DS0212 was defined. This is because PCHOC was likely influenced directly by the increases in prices of both, cocoa and non-cocoa confectionary materials while PNOCHOC was likely directly affected by the rise in prices of non-cocoa confectionary materials.

improved specification. Ultimately, all four were included in the cointegration space and in differenced form in the short run/deterministic component of the unrestricted VEC in equation 2.

The second set of sequential estimations aimed to further improve specification obtained from the unrestricted VEC with the three permanent shift dummy variables (DS9907, DS0101, DS0212) and a trend in the levels-based, long run and difference-based short run/deterministic components of equation 2. More specifically, the second set of estimations captured the non-normal influences of specific extraordinary events through the use of transitory ("blip") outlier dummy variables. Each time a potential outlier was deemed potentially disruptive because of a "large" standardized residual,[9] an appropriately specified dummy variable was included in equation 2's short run/deterministic component[10] and ultimately retained if it generated a statistically strong coefficient t-value and/or if the array of diagnostic values moved in favorable patterns indicative of improved specification. A new estimation and analysis of the array of diagnostic variables is conducted for each and every new observation-specific dummy variable included. Ultimately, 13 observation-specific dummy variables were included.[11]

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[9] We followed a procedure for examination and analysis of potential outlier dummy variables recommended by Juselius (2004, chapter 6). An observation was judged as an "extraordinary" one or an "outlier" if it generated a standardized residual within the 3.0-3.5 range. More specifically, such a criterion for outliers was designed based on the sample size using the Bonferoni criterion: INVNORMAL[1.0 – 0.025) $^{(1/T)}$], where INVNORMAL is the RATS instruction for the inverse of the normal distribution function that returns the variable for the c-density function of a standard normal distribution (Estima 2005, p. 503). Here, the Bonferoni value equals 3.5 for sample size T=147. All observations with standardized residuals with an absolute value of from 3.0 to 3.5 or more were considered outliers and observation-specific transitory dummy variables were specified for these. They were then placed into equation (2)'s short run/deterministic component, an estimation was implemented, and the outlier variable was retained if the variable's coefficient was statistically significant and/or if there was a favorable movement in the grid of diagnostic values indicative of improved specification. We exercised some leeway on identifying outliers using the Bonferoni criterion value of 3.5. In several instances, clearly problematic standardized residuals were nearer the value of 3.0 than 3.5, leading to our formulation of the range criterion of 3.0-3.5.

[10] One does not place transitory dummy variables aimed at capturing the effects of outlier observations in the long run cointegration space; such observation-specific dummy variables are included in the short run/deterministic component of equation (2) (see Juselius 2004, chapter 6). Observation-specific dummy variables may take on an array of different specifications depending on the pattern of the outlier behavior of the equation's residuals. See Juselius (2004, chapter 6) for an explanation of the well-known forms of outlier dummy variables and for discussion on which sorts of shift dummy variables are included in the cointegration space.

[11] To conserve space, we have not included the extensive variable-by-variable analysis from numerous estimations which resulted in inclusion of the 13 outlier dummies. All included outlier dummy variables were of the transitory "blip" format described in Juselius (2004, chapter 6). This form is appropriate for the short run/deterministic component of the model and take on a value of 1.0 for the outlier observation, followed by a value of -1.0, and a value of zero otherwise. The 13 included observation-specific transitory blip dummy variables were defined for the following observations: 1992:07, 1992:12, 1993:09, 1994:03, 1994:06, 1995:08, 1996:01, 1996:08, 1999:11, 2000:03, 2000:07, 2000:10, 2004:01. The extraordinary effects captured by the outliers associated with the 1992:07, 1992:12, and 1993:09 observations likely arose from large expected and realized increases in sugar and sugar beet production from increases in planted area and yields during fiscal 1992/1993 (USDA, ERS 1993, p. 9). The outliers for 1994:03, 1994:06, and 1995:08 were likely associated with added observation-specific and extraordinary influences elicited after the January, 1994 implementation of the Uruguay Round of WTO trade negotiations and the January 2005 implementation of the NAFTA trade agreement. Major U.S. farm policy changes of the 1996 farm bill (e.g., the FAIR Act) likely generated extraordinary and month-specific effects defined for 1996:01 and 1996:08. The five outliers defined for 1999:11, 2003:03, 2000:07, 2000:10, and 2004:01 may reflect additional disturbances on an observation-specific basis over and beyond the influences generated by the four U.S. sugar policy changes, the 2001 cocoa price increase, and the late-2002 rise in non-cocoa confectionary input costs during the 1999:07-2004:03 subperiod for which the shift dummy variable DS9907 was aggregately defined.

Equation (2) was deemed adequately specified to proceed with exploiting cointegration with the following: a trend and three permanent shift dummies included in the levels-based and short run/deterministic component, and with 11 seasonal and 13-observation-specific dummy variables included in the short run/deterministic component.[12] Table 1 provides evidence of adequate specification.

Table 1 provides an array of diagnostic values focused on specification for two model estimations: the initially estimated unrestricted VEC before the sequential estimations and for the unrestricted VEC model judged as adequately specified after inclusion of the trend, three permanent shift dummy variables, 13 outlier dummy variables, and 11 centered seasonal variables. Results displayed in table 1 clearly demonstrate a remarkable improvement in specification and demonstrate the benefits of focusing intense scrutiny on the properties of the modelled series – properties which Juselius maintains are often not adequately considered.[13] Evidence suggests that the effort at achieving adequate specification increased the model's ability to explain variation by more than 50 percent, insofar as the trace correlation, a system-wide goodness of fit indicator, rose from 0.43 to 0.66. As well, ARCH effects did not appear to be a serious problem.

There were markedly favorable movements in most equations' residual behavior towards statistically normal behavior, as evidenced by the univariate Doornik-Hansen test values. The Doornik-Hansen value tests the null hypothesis that the relevant equation generates residuals which are statistically normal (Juselius 2004, chapter 4).[14] Such favorable movement is aggregately evident from four of six equations having generated non-normal residuals prior the specification effort, whereas five of six apparently generated normally behaving residuals after the specification effort (table 1). The equation for raw sugar price benefited noticeably from the specification efforts, with the Doornik-Hansen value falling from a highly untenable 66.8 value initially to 6.8, well below the critical value, after the effort at unrestricted VEC specification. As well, there were other notable declines in Doornik-Hansen values: from 19.6 to 1.7 for the PNOCHOC equation and from 12.9 to 2.7 for the PBAKERY equation.

Table 1 also provides indications on skewness and kurtosis of each equation's residuals. Normal behavior suggests that skewness values should be as near to zero as possible with acceptable (absolute) values being about unity or less; and that kurtosis values should be as near to 3.0 as possible with values within the range of 3.0 and 4.0 being acceptable (see Juselius 2004, chapter 4). After the effort at improved specification, five of the six skewness values improved substantially and all six ultimately were within a range of zero considered reasonable. Table 1 also suggests that the specification efforts resulted in declines in the kurtosis values, and five of the six were within the 3.0-4.0 range considered reasonable.

Following Juselius (2004), these diagnostics were deemed acceptable, even though one of the six equations, that for chocolate-based confectionary product price, was problematic throughout. PCHOC's non-normal residual behavior clearly arose from the 2001 slope shift shown and discussed in figure 3.

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[12] Each equation was estimated over the 1992:03-2004:03 sample (147 observations) with 101 degrees of freedom.

[13] Dr. Katarina Juselius made this point during the econometrics course on cointegrated VAR methods. The point is that many applications of time series econometric techniques are done without getting an adequate handle on the properties of the data being modelled. One of our primary aims was to present the diagnostic results in table 1 and show the value of so-considering the data series properties when specifying VAR and VEC models. The course: "Econometric Methodology and Macroeconomic Applications, the Copenhagen University 2004 Econometrics Summerschool," instructed by Drs. Katarina Juselius, Soren Johansen, Anders Rahbek, and Heino Bohn Nielsen, Aug. 2-22, 2004, Institute of Economics, Copenhagen University, Denmark.

[14] Each Doornik-Hansen value is distributed as a chi-square variables with 2 degrees of freedom and a critical value of 9.2 (1 percent significance level).

Table 1
Mis-specification tests for the unrestricted VEC: Before and after specification efforts

Test and/or equation	Null hypothesis and/or test explanation	Prior efforts at specification adequacy	After efforts at specification adequacy
Trace correlation	System-wide goodness of fit: large proportion desirable	0.43	0.66
ARCH(4) test for heteroscedasticity (lag 4)	Ho: no heteroscedasticity by 4th lag for system. Reject with p-values less 0.05	40.40 (p=0.28)	33.09 (p=0.61)
Doornik-Hansen test for normal residuals (univariate)	Ho: equation residuals are normal. Reject for values above 9.2 critical value		
ΔQSUGAR		4.9	7.2
ΔPRAW		66.8	6.8
ΔPCHOC		26.6	22.6
ΔPNOCHOC		19.6	1.7
ΔPSOFT		7.5	4.9
ΔPBAKERY		12.9	2.7
Skewness(kurtosis) univariate values	Skewness: ideal is zero; “small” absolute value acceptable kurtosis (in parentheses): ideal is 3.0; acceptable is 3-5.		
ΔQSUGAR		0.26 (3.7.)	0.44 (3.97)
ΔPRAW		-0.75 (8.73)	-0.008 (3.9)
ΔPCHOC		1.24 (6.78)	0.62 (5.61)
ΔPNOCHOC		1.00 (5.58)	0.25 (3.13)
ΔPSOFT		-0.13 (3.98)	-0.16 (3.72)
ΔPBAKERY		-0.22 (4.44)	-0.16 (3.44)

The efforts did improve PCHOC’s specification, but not to a degree needed for evidence to suggest approximately normal behavior of the estimation’s residuals. Summarily, table 1 shows clear and substantial progress from efforts on specification improvement, and that the entire system generates residuals which generally approximate statistically normal behavior. An adequately specified unrestricted VEC model has been achieved with which to exploit the system’s cointegration properties. Table 1's favorable movement in the grid of diagnostic values clearly demonstrates the benefits of having seriously considered the data.

Cointegration: Determining and Imposing Reduced Rank on the Cointegration Space

Juselius (2004, p. 86) notes that cointegration implies that there are certain linear combinations of the six individually nonstationary variables that are integrated of an order lower than itself. And in this paper’s context, where all six sugar-based variables of the vector process are (later) shown to be integrated of order 1 or I(1), then cointegration implies that a single difference of the (logged) levels data renders the six series, and the vector, integrated of order zero or I(0). Cointegrated variables are driven by the same persistent shocks, and should the nonstationarity of one variable correspond to the nonstationarity in another, then there may be from one to five stationary linear combinations among the six nonstationary sugar-based variables (Juselius 2004, p. 86).[15] Cointegrated variables share common stochastic and deterministic trends, and tend to move together or in tandem through time in a stationary manner even though the six composite sugar-based series are each non-stationary (Juselius 2004, p. 86; Johansen and Juselius 1990, 1992).

Reconsider the unrestricted VEC in equations 2 and 3. Insofar as x(t) and x(t-1) are I(1) or nonstationary, then Δx(t-1) must be stationary or I(0). Equation 2 can clearly hold under three settings:

- First, the rank of Π can be zero, in which case the entire levels-based, long run component is zero; the six sugar-based variables do not share common trends or move together in time; and a VAR in first differences with all long run information jettisoned would be appropriate. For sugar-based variables and from visual inspection of figures 1-6, this is unlikely.

- Second, the rank of Π could be full (here rank p=6), whereby the system is fully stationary and the six variables would be appropriately modelled as a VAR in levels (equation 1). This cannot be the case as each of the variables are I(1), such that equation 2 could not hold: the right side could not be stationary as the levels-based component is I(1).

- And third, the rank of Π could be reduced (rank of from one to five). In this case, equation 2 could hold even if all six series are individually I(1), as the levels-based long run component would be non-zero but stationary nonetheless (Juselius 2004, p. 86-87). This third case reflects cointegration.

As previously defined in equation 3, and if the variables are contegrated as in the third bullet above, then Π has reduced rank $r < p$. Under these conditions, β'*x(t) is stationary or I(0) even though each of the six sugar-based series are (later) shown to be nonstationary (Juselius 2004, p. 87).

Determination of cointegration rank is a four-tiered process. First, one conducts the trace tests summarized in Johansen and Juselius (1990, 1992). Second, rank-relevant information emerging from an examination of the companion matrix's characteristic roots should be considered. Third, one should consider average cycle durations of the monthly data, and econometric results on relevant α-coefficients. And fourth, an inspection of the plotted cointegrating relations should be examined for stationarity properties.

Nested trace tests and other evidence for rank determination of the error-correction matrix

Table 2 provides trace test evidence for rank determination. Trace tests are corrected with Bartlett's adjustment factor for small samples, while the 95 percent fractile values were adjusted for restriction of three permanent shift dummies into the cointegration space (see table 2 notes and Juselius 2004, chapter 8). Tests are nested and begin atop of the table. Evidence at the 95-percent significance

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[15] If the system is comprised of six individually stationary variables, then there are six stationary cointegrating relations – one for each of the endogenous variables. In such cases, cointegration is not an issue as the system is already stationary and a VAR model in levels would be appropriate.

Table 2
Trace test statistics and related information for nested tests for rank determination

Null hypothesis	Eigen value	Bartlett-corrected trace value	95 (percent) fractile (critical value)	Result
Rank or r ≤ 0	0.3678	198.3	122.9	Reject null that rank is zero.
Rank or r ≤ 1	0.344	140.5	94	Reject null that rank is less than or equal to 1
Rank or r ≤ 2	0.2375	84.4	69.1	Reject null that rank is less than or equal to 2
Rank or r ≤ 3	0.1565	45.3	47.9	Fail to reject null that r rank or r ≤ 3
Rank or r ≤ 4	0.092	17.9	31.1	Fail to reject null that rank or r ≤ 4
Rank or r ≤ 5	0.0764	9	17.9	Fail to reject that rank or r ≤ 5

Notes.—The trace test values are corrected for small samples with the Bartlett adjustment generated by the Cointegration analysis of Time Series-2 (CATS2) program. As recommended by Juselius (2004, p. 171), CATS2-generated fractiles are increased by (3 times 1.8) or 5.4 account for the 3 shift dummy variables restricted to lie in the cointegration relations.

level is sufficient to reject the first three nested null hypotheses, and fails to reject the fourth null, that rank is 3 or less. Taken alone, this evidence suggests that there are three long run cointegrating relations which error-correct the system of six individually nonstationary series to move tandemly through time. Evidence generated by the fourth hypothesis test (rank=3 or less) may be of border line strength as the trace value of 45.3 approached the corrected fractile of 47.9. As a result, sole reliance on the results from the trace test in determining rank is not recommended (Juselius 2004, chapter 8).

Table 3 and figure 7 provide information on the companion matrix's roots for the estimated VAR model. If there are r=3 cointegrating relations towards which the process is adjusting, then there are p-r or three common trends pushing the system (Juselius 2004, p. 173). If r=3 is an appropriate choice, then there should be three unity-valued characteristic roots with the fourth being statistically sub-unity.[16] One would prefer a situation where the estimated eigenvalues are either very large or very small such that reliability is enhanced that the trace test is not confronted by overly problematic sample size and test power problems (Juselius 2004, pp. 173-174). There may be problems here because the fourth root, 0.85 in table 3 is not "very small," approaches unity, and is likely a "borderline" case. Evidence that the fourth root is more of a statistically sub-unity than unity value reinforces the appropriateness of having chosen rank as r=3 (Juselius 2004, chapter 8).

Evidence from the third cointegrating relation's adjustment speed or α-coefficients suggests that the third relationship is a viably error-correcting one; that the choice of r=3 for the rank of Π and the number of cointegrating relations includes three full participants in the error-correction process; and that the borderline fourth root of 0.85 (table 3) is indeed more of a sub-unity than unity value. This is because some of the third relation's α-coefficients are statistically significant, suggesting that the relation's inclusion results in gains/contributions to the error-correction process (Juselius 2004, pp. 275). PNOCHOC's α coefficient appears highly significant, while the α coefficients of PRAW and PSOFT also achieve significance.[17]

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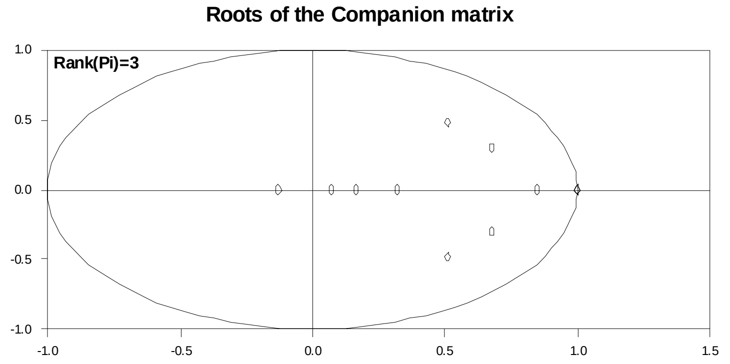
[16] If r=3 should incorrectly include a nonstationary linear combination as a cointegrating relation, then the fourth characteristic root would be statistically more unity than subunity, that is would be "large," and r should be reduced (Juselius 2004, p. 174).

[17] To conserve space, we do not provide all of the cointegration results for the pre-final unrestricted VEC model. Note that the third cointegration relation's alpha vector is as follows, with t-values: ΔQSUGAR, -0.0053, t= -1.73, ΔPRAW, -0.0041, t= -2.30, ΔPCHOC, 0.0004, t=0.29, ΔPNOCHOC, 0.001, t=3.72; ΔPSOFT, 0.001, t= 2.50, and ΔPBAKERY, 0.0006, t= 1.82. The "Δ" denote differences.

Table 3
Roots of the Companion Matrix, Rank = 3

	Real	Imaginary	Modulus	Argument
Root 1	1.0000	0.0000	1.0000	0.0000
Root 2	1.0000	0.0000	1.0000	0.0000
Root 3	1.0000	0.0000	1.0000	0.0000
Root 4	0.8488	0.0000	0.8488	0.0000
Root 5	0.6787	0.3023	0.7429	0.4191
Root 6	0.6787	-0.3023	0.7429	-0.4191
Root 7	0.5110	-0.4832	0.7033	-0.7575
Root 8	0.5110	0.4832	0.7033	0.7575
Root 9	0.3209	-0.0000	0.3209	-0.0000
Root 10	0.1629	-0.0000	0.1629	-0.0000
Root 11	-0.1281	-0.0000	0.1281	-3.1416
Root 12	0.0695	-0.0000	0.0695	-0.0000

Figure 7
Characteristic roots of the companion matrix, unrestricted VEC



Further support that the fourth root of 0.85 is sub-unity and the choice of r=3 is appropriate arises when the model's average cycling duration reasonably short. Cycles of mean-reverting behavior average six or seven months, which is deemed of reasonable brevity with monthly data.[18]

The graphed plots of the three cointegrating relationships in figures 8, 9, and 10 suggest that, within reason, the relationships behave in patterns that approximate stationarity: where behavior is frequently "reversive" to the zero mean in cycles that are not excessively enduring (see Juselius 2004, pp. 172-176). The $\beta'*X(t)$ plots are those from the model that incorporates short run effects, while the $\beta'*R(t)$ plots are those from the "concentrated" model corrected for the short run effects. That the three cointegrating relations are stationary suggests that the choice of r=3 renders three relationships that are indeed associated with the stationary components of the model. Juselius (2004, chapter 8) recommends focusing on the $\beta'*R$ plots. The first cointegrating relationship seems reasonably stationary aside from problems with an apparent outlier in 1999. The third relationship displays apparent stationary behavior throughout most of the sample mean-reverting behavior, despite a subperiod of relatively

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[18] According to Juselius, 1.0 less the near-unity root of 0.85 equals 0.15, which, when divided into 1.0 provides 6.7, a value reflecting average cycling lengths of 6-7 months. Private communication with K. Juselius with an author, University of Copenhagen, Denmark, August, 2004. Also see Juselius (2004, pp. 172-174).

Figure 8
Plotted cointegrating relation 1, unrestricted VEC: Versions with and without correction for short run effects

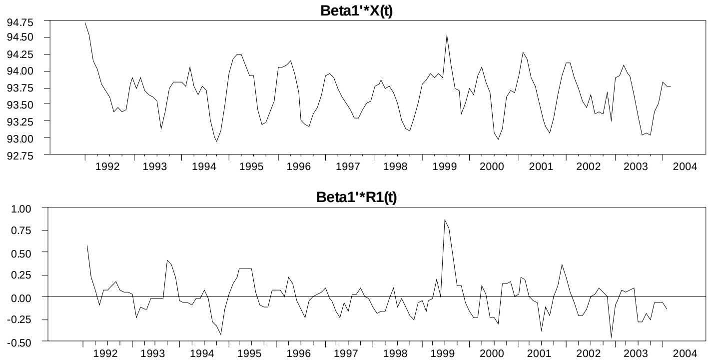


Figure 9
Plotted cointegrating relation 2, unrestricted VEC: Versions with and without correction for short run effects

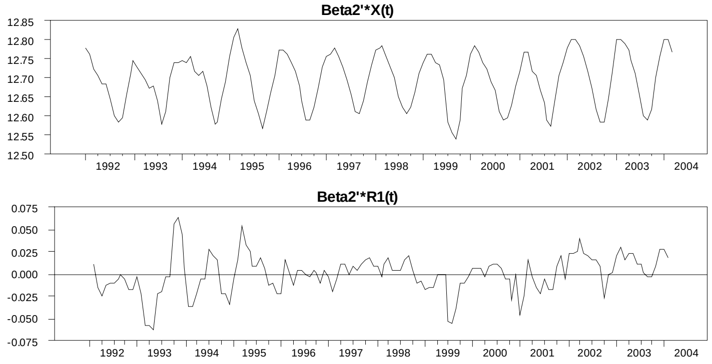
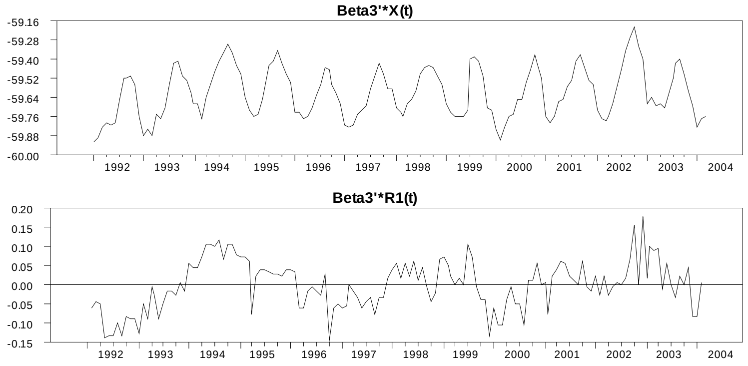


Figure 10
Plotted cointegrating relation3, unrestricted VEC: Versions with and without correction for short run effects



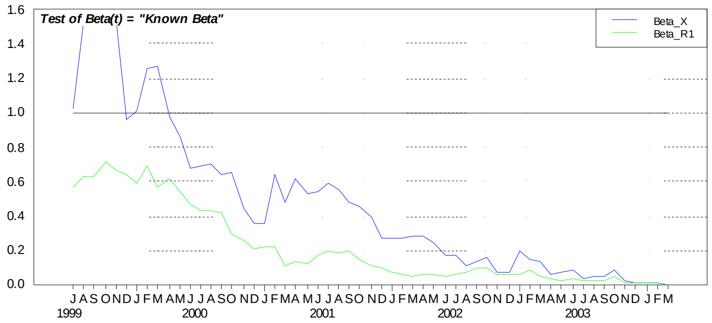
nonstationary behavior in the beginning of the sample. Of the three plotted relationships, the second (figure 9) is most problematic, with longer and wider cycles in the first third of the sample. Nonetheless, even the second plotted relationship in appears to stabilize with increasingly frequent reversion towards the zero mean in shorter cycles in the last two-thirds of the sample.

As Juselius (2004, pp. 172-176) cautioned, determining rank at three was not straightforward in this monthly study of small samples with a fourth and potentially near-unity root in the companion matrix. However, we conclude that a rank of three is probably appropriate, after having considered the trace tests and other evidence noted above.

Test for parameter constancy

Figure 11 provides the recursively calculated “known beta” test of parameter constancy provided by the CATS2 software written and detailed in Juselius (2004, pp. 186-190). These methods test if there is parameter constancy or time-invariance of estimated parameters (also known as a lack of statistical “structural change”). The method tests if the full-sample “baseline” model’s cointegration relations could have been accepted as those of each recursively estimated model over the 1999:07–20004:03.[19] Plots of known beta values are provided for two versions of the model: the version incorporating short run effects (β’*X in figure 11) and for the concentrated version which corrects for the short run influences (β’*R plots in figure 11). Known beta values should ideally be unity or less for both version plots, with those of the concentrated model being more reliable (Juselius 2004, pp. 186-190). Since most of the uncorrected model’s plots and all of the concentrated model’s plots are unity or less, evidence suggests that time-variance of parameters and hence statistical structural change is not a serious problem.

Figure 11
Recursively calculated “known beta” test of parameter constancy



The test statistic is scaled by the 5% critical value

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[19] Analysis of the data patterns in figures 1-6 (especially figure 2) suggested that 1999:07–2004:03 is a logical subperiod over which to estimate recursively, observation by observation, to discern if time-variance of parameters is present. This subsample period encompassed many influential policy and confectionary market events which could have induced statistical structural change.

Summary of the maximum likelihood estimator of the cointegration space[20]

Johansen (1988), Johansen and Juselius (1990), and Juselius (2004, chapters 8-10) derive and summarize a method of maximum likelihood estimation of the cointegration space when, as explained below, there are nonstationary elements in the modelled vector that cointegrate and error-correct the system back towards the long run equilibrium after short run shocks or disturbances. A brief summary of this well-known estimator is provided. These methods are used to impose statistically-supported α- and β-coefficient restrictions which emerged from the rank-restricted cointegrated VEC model.

The Frisch-Waugh theorem is invoked within the context of our unrestricted VEC in equation 2 is re-displayed here as equation 2a (Johansen and Juselius 1990, 1992; Juselius 2004, chapter 7):

(2a) $x(t) = \Gamma 1 * \Delta x(t-1) + \Pi * X.(t-1) + \Phi * D(t) + \epsilon(t)$, $\epsilon(t)$ distributed as white noise.

Because of inclusion of the various trend and dummy variables, some of the dimensions associated with the initially displayed equation 2 have changed. In equation 2a, the Π matrix has dimensions of p1 x p1 or 10 x 10 since, in addition to the six sugar-based variables, the cointegration space includes three shift dummies and a trend.

One first regresses $\Delta x(t)$ on $[\Delta x(t-1)$ and $D(t)]$, the short run/deterministic model component (Juselius 2004, chapter 7):

(4) $\Delta x(t) = f[\Delta x(t-1), D(t)] + R(0t)$

This renders $R(0t) = \Delta x(t) - f[\Delta x(t-1), D(t)]$ which is a “concentrate” of VAR(2)’s current short run components “cleansed” of the noisy short run dynamic/deterministic influences (Juselius 2004, pp. 126-128). One then conducts a second regression of the VAR(2)’s long run levels components on the same vector of noisy short run/deterministic components (Juselius 2004, pp. 126-28):

(5) $x(t-1) = g[\Delta x(t-1), D(t)] + R(1t)$

This provides $R(1t) = x(t-1) – g[\Delta x(t-1), D(t)]$ which is a “concentrate” of the VAR(2)’s long run, theory-embedded components also “cleansed” of the noisy short run dynamic/deterministic influences (Juselius 2004, pp. 126-28).

And third, one regresses:

(6) $R(0t) = \Pi * R(1t) + \epsilon(t) = \alpha\beta' * R(1t) + \epsilon(t)$

This “R-model” provides super-consistent estimates of the error-correction mechanism, the $\Pi = \alpha\beta'$ coefficient on R(1t) (Juselius 2004, pp. 126-128). The mechanism captures exclusively the relationships with which the system error-corrects towards the long run steady state in response to a transitory shock.

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[20] The material presented in this section is well-known and was developed by Johansen (1988) and Johansen and Juselius (1990, 1992), among others of their articles. As well, Juselius (2004, chapters 8-10) provides a thorough summary of this estimator. This subsection draws heavily on this seminal work.

As detailed in Johansen and Juselius (1990, 1992) and Juselius (2004, pp. 128-29), a maximum likelihood estimator is derived in two additional steps, and being well-known, is not re-derived here.[21] Solutions and establishment of this maximum likelihood estimator evolves into a formulation of an eigenvalue problem which renders p-ordered eigenvalues expressible as the determinant of the residual covariance matrix (Juselius 2004, p. 130). With “hat” denoting estimated values, the magnitudes of the ordered eigenvalues [(λ-hat(1) 〉 . . . 〉 λ-hat(6)] are each associated with the stationarity of the six potential cointegrating relations, with the larger values being most stationary (Johansen and Juselius 1990, 1992; Juselius 2004, p. 130). One then conducts hypothesis tests on each of the six eigenvalues by applying Johansen and Juselius’ (1990, 1992) well-known trace tests with values constructed with the eigenvalue estimates.

The three cointegrating relationships which emerged from imposing rank using this reduced-rank estimator are equations 7, 8, and 9 below. Note that these estimates not yet restricted for evidentially supported economic restrictions which emerge from the next section’s hypothesis tests.

$$(7)\ \mathrm{QSUGAR} = -4.55*\mathrm{PRAW} - 4.7*\mathrm{PCHOC} - 22.8*\mathrm{PNOCHOC} - 9.45*\mathrm{PSOFT} + 16.8*\mathrm{PBAKERY} - 0.85*\mathrm{DS9907} + 0.10*\mathrm{DS0101} + 0.87*\mathrm{DS0101} + 0.03*\mathrm{TREND}$$

$$(8)\ \mathrm{PCHOC} = -0.26*\mathrm{QSUGAR} + 0.26*\mathrm{PRAW} - 0.32*\mathrm{PNOCHOC} - 1.3*\mathrm{PSOFT} + 0.47*\mathrm{PBAKERY} + 0.07*\mathrm{DS9907} + 0.02*\mathrm{DS0101} + 0.07*\mathrm{DS0212} + 0.004*\mathrm{TREND}$$

$$(9)\ \mathrm{PRAW} = +0.42*\mathrm{QSUGAR} - 0.10*\mathrm{PCHOC} + 9.62*\mathrm{PNOCHOC} + 4.84*\mathrm{PSOFT} - 2.96*\mathrm{PBAKERY} - 0.26*\mathrm{DS9907} + 0.12*\mathrm{DS0101} - 0.13*\mathrm{DS0212} - 0.01*\mathrm{TREND}.$$

Hypothesis Tests and Inference on the Economic Content of the Three Cointegrating Relations

The goal is to begin with equations 7 – 9 above, the three unrestricted cointegrating vectors, and conduct a series of hypothesis tests on the $\alpha\beta' = \Pi$, and then impose those restrictions that are statistically supported by the hypothesis test evidence (Juselius 2004, chapter 10). Johansen and Juselius [1990, pp 194-206) and Juselius (2004, chapter 10) detail these test procedures.

Hypothesis tests on the beta coefficients take the form:

$$(10)\ \beta = H*\varphi,$$

where β is a p1 x p1 vector of coefficients on variables included in the coingetration space; H is a p1 x s design matrix, with “s” being the number of non-restricted or “free”beta coefficients (Juselius 2004, pp. 245-248); and φ is an s x r matrix of the unrestricted beta coefficients. Johansen and Juselius’ (1990, 1992) well-known hypothesis test value or stastistic is provided in equation 11:

$$(11)\ -2\ln(Q) = T*\Sigma\ln[(1-\lambda_i^*)/(1-\lambda_i)],\ \text{for } i = 1,2, \text{ and } r=3.$$

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[21] See Juselius (2004, pp. 126-30). Summarily, one first assumes that matrix β is known; derives an α estimator under the assumption that β’R(1t) is known; and then inserts $\alpha = \alpha(\beta)$ in the maximum lkkelihood function to render it a function of β and not of α. A β-estimate (β-hat) emerges to maximize the likelihood function. One secondly uses the maximum likelihood β-estimator to calculate α-hat = α(β-hat) where, again, “hat” denotes estimates.

The asterisked (nonasterisked) eigenvalues are generated by the model estimated with (without) the tested restriction(s) imposed.

Likewise, hypothesis tests concerning the α or adjustment speed coefficients permit a characterization of relative speeds of error-correcting adjustment with which the system responds to a given shock (Johansen and Juselius 1990, 1992; Juselius 2004, chapter 11). The null hypothesis is in equation 12:

(12) $H(0)\text{:}\ \ \alpha = A^*\psi$

Above, A is a p x s design matrix; s is the number of unrestricted coefficients in each of the r=3 columns of the α matrix; and ψ is the s x r matrix of the non-restricted or "free" adjustment speed coefficients (Juselius 2004, chapter 11). Equation 11's test statistic also applies here, and is distributed asymptotically as a chi-squared distribution with degrees of freedom equal to the number of imposed coefficient restrictions (Juselius 2004, pp. 206-207 and 211-213). Three sets of hypothesis tests on the betas, followed by tests on the alphas, are provided below.

Hypothesis tests on the betas

There are three sets (groups) of hypothesis tests on the beta coefficients. The first group of six tests examines if each endogenous variable is stationary under the imposed rank of three. Second, given that each of the cointegrating relations has p1 or 10 variables (six endogenous variables, 3 permanent shift dummies, and a linear trend), there are the 10 "exclusion hypotheses" of whether each variable is zero in the three cointegrating relations. Given the results of these two test sets, a third set of sequential hypothesis tests on individual beta estimates is provided on equations 7, 8, and 9 with any statistically significant stationarity and/or exclusion restrictions from test sets 1 and 2 imposed.

Tests of stationarity

Juselius (2004, pp. 220-222) recommends a system-based likelihood ratio test of each individual endogenous variable's stationarity within a system setting and given the imposed rank (here r=3). She recommends such a test over univariate stationarity tests (e.g., Dickey-Fuller tests) which are independent of the cointegrated system's chosen rank. Basically, the recommended likelihood ratio tests examine whether each endogenous variable itself constitutes a separate stationary cointegrating relation, with a unity value for the tested variable's betas (as well as unity for the betas on the four deterministic variables restricted to the cointegration space).[22] Equation 10 takes the following form (Juselius 2004, p. 221):

(13) $\beta^c = [b,\varphi]$

Above, β^c is the p1x r (or 10 x 3) beta matrix with one of the variable's levels restricted to a unit vector; b is a p1 (or 10) x 5 vector with a unity value corresponding to the relevant variable whose stationarity is being tested and for the four deterministic components retained in the cointegration space; and φ is a p1 x (r-1) or 10 x 2 matrix of the remaining two unrestricted cointegrating vectors (Juselius 2004, p. 221). With four deterministic components retained and the imposed rank of r=3, then equation 11's test value is

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[22] This test can be conducted in CATS2 in two settings: with and without inclusion of these four deterministic variables restricted to the cointegration space: DS9907, DS0101, DS0212, and TREND. We chose to include these four deterministic variables in the tests, due to the importance of the events for which the variables were defined.

distributed under the null of stationarity as a chi-squared variable with 3 degrees of freedom. Evidence was sufficient to reject that each of the six endogenous variables was stationary.[23]

Tests of Beta Exclusions

Ten exclusion tests examine whether each of the p1=10 variables have zero coefficients in the model's three cointegrating relations. Failure to reject the null that a variable's betas are zero-valued suggests that the variable should be excluded from the cointegration space but possibly remain in the short run/deterministic component. The hypothesis test (equation 10) would include a p1 x 3 β-vector; a p1 x 9 design matrix H, with 9 being the number of unrestricted beta coefficients in each relation; and a 9 x 3 matrix φ of the nine unrestricted coefficients in each of the three cointegrating relationships (Juselius 2004, chapter 10).[24] In all cases except the β coefficients on DS0101, the test values displayed evidence of statistically nonzero coefficients in the r=3 cointegrating relations.[25] This evidence supports the validity of the inclusion of the 6 variables as participants in the error correction process, as well as the validity of restricting a linear trend and the DS9907 and the DS0212 permanent shift dummy variables, into the cointegration space. Based on additional evidence from the unrestricted VEC's Π estimates and market knowledge, we opted to also include DS0101 coefficients in the cointegrating relationships, despite the low test value of its hypothesis test of exclusion.[26]

Set of Sequential Hypothesis Tests on Individual Beta Coefficients

When the model is estimated with stationary data, one must identify the long run structure of the three cointegrating relations which emerged as equations 7, 8, and 9 after having imposed rank on the cointegration space of the adequately specified unrestricted VEC (Juselius 2004, pp. 245-246). Under the rank condition of identification, one identifies the three cointegrating relations by imposing at least r-1 or 2 restrictions on each of the three relationships in equations 7, 8, and 9 (Juselius 2004, pp. 245-246).

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[23] Given the rank of 3, the test values and parenthetical p-values are as follows, with the null of stationarity rejected for "small" p-values: 23.0 (0.0000) for QSUGAR, 7.4 (0.06) for PRAW, 12.4 (0.006) for PCHOC, 11.5 (0.009) for PNOCHOC, 22.6 (0.0000) for PSOFT, and 15.9 (0.001) for PBAKERY. PRAW's result is borderline and we deemed the variable stationary because of the clear elements of nonstationarity which emerged from the data analysis (figure 2), and since the stationarity test without the four deterministic components suggested stationarity, with a test variable of 28.6 (0.0002). Treating PRAW as stationary seemed appropriate given that the test value was so close to the critical value and because of this other evidence.

[24] Basically, the φ-matrix is the β-batrix without the betas of the variable being tested for exclusion.

[25] The test values (each distributed as a chi-square distribution with 3 degrees of freedom) and parenthetical p-values were as follows, with the null of a variable's three zero-valued beta coefficients being rejected for p-values of 0.05 or less (that is, for 5%): 20.6 (0.0001) for QSUGAR; 30.7 (0.0000) for PRAW, 37.2 (0.0000) for PCHOC; 21.5 (0.0001) for PNOCHOC; 22.7 (0.0000) for PSOFT; 23.4 (0.0000) for PBAKERY; 26.5 (0.0000) for DS9907; 23.0 (0.0000) for DS0212; and 10.1 (0.0003) for TREND. The test value for DS0101's coefficients equalling zero was 4.8 (0.19) which suggests that evidence at the 5 percent level was insufficient to reject the null hypothesis that β(DS0101) had betas in the 3 cointegrating relations were zero.

[26] Of the six DS0101-related elements in the Π matrix restricted for a reduced rank of r=3: four were statistically nonzero at the 5% level and 5 were statistically nonzero at the 10-percent level, suggesting that the DS0101 dummy variable defined to capture the 2001 sustained rise in cocoa prices and the late-2002 rise in prices of other confectionary product inputs was important to the error correction process. As well, market experts suggested that inclusion of this DS0101 was probably important to this cointegrated system. These points were based on two emails from a USITC industry analyst responsible for monitoring markets for sugar and sugar-containing products. Emails were received Aug. 18 and 20, 2004.

One generally takes equations 7, 8, and 9, and chooses testable restrictions which coincide with market knowledge, make theoretical sense, are suggested by the unrestricted estimates, and/or meet the rank condition of identification using equation 10 with the test value calculated with equation 11.[27] Those which evidence fails to reject are retained, and the Johansen-Juselius reduced rank estimator re-estimates the three relations with the last-accepted restriction(s) imposed, assuming that these accepted relations are enough to identify the system. One repeats this process sequentially to obtain a set of finally-restricted cointegrating relationships. Restrictions were accepted for high p-values (above 0.05).

This process is lengthy and multi-iterative and is summarized in table 4. Following Juselius' (2004, chapters 10-12) procedures, we first tested those economically interesting hypotheses which were very evident from the unrestricted estimates in equations 7, 8, and 9: tests on whether the betas on PRAW and PCHOC are equal in the first relation or equation 7 (along with restrictions necessary to identify the system) comprising "test set 1," and tests on whether the betas on QSUGAR and PRAW in the second relation (equation 8) are negatively related and equal in absolute value (along with conditions necessary to identify the system) comprising test set 2. Evidence in table 4 was sufficient to reject test set 2 (test statistic's p-value of 0.049) and insufficient to reject test set 1 (test statistic's p-value of 0.128). Thereafter, we retained all of these set-1 restrictions in table 4, re-estimated the system using the Johansen-Juselius reduced-rank estimator, and then conducted a stream of sequential and additive tests on the three re-estimated cointegrating relations. We concentrated on emergent testable hypotheses in cointegrating relations 1, 2, and then 3 in that order. Each sequential test focused on an additional and testable restriction that became evident from beta coefficient results of the prior re-estimation (Juselius 2004, chapters 10-12). Because of space limitations, the sequential process of testing additional hypotheses after imposition of test set 1' restrictions is only summarized in table 4, and without the various re-estimations' results: only the final three cointegrating relations are provided below as equations 14, 15, and 16.

After having rejected test set 2 and having re-estimated equations 7, 8, and 9 with the accepted restrictions (test set 1) imposed, a number of testable hypotheses emerged. Because of an insignificant β(DS0212) t-value, the first and most obvious testable hypothesis was that β(DS0212) = 0 in the first cointegrating relation, and this test was added to form test set 3 (table 4).[28] Evidence was insufficient to reject test set 3 (test statistic p-value of 0.22), and this led to the retention of a zero restriction on β(DS0212) in relation 1 (equation 7), and the re-estimation of the system using the Johansen-Juselius reduced-rank estimator. No further testable hypotheses on the first cointegrating relation emerged, such that we next considered testable hypotheses on the second cointegrating relation. This process was repeated on cointegrating relations 2 and 3 in succession so as to comprise test sets 4 and 5. The re-estimations were implemented for test sets 4 and 5, and evidence was insufficient to reject the added restrictions, as table 4's test statistic p-values in sets 4 and 5 exceeded 0.05.

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[27] This third set of beta hypothesis tests should be conducted while retaining any statistically supported restrictions from the stationarity and exclusion hypothesis tests done above. Since evidence rejected all stationarity and exclusion restrictions, no restrictions carried over to this third set of hypothesis tests. So in effect, the third set of hypothesis tests on individual betas were applied directly to equations 7, 8, and 9.

[28] Generally, we incrementally tested one added restriction at a time, and, if accepted by the evidence, this restriction was imposed with the prior-accepted ones, and the Johansen-Juselius reduced-rank estimator summarized above was used to re-estimate the three cointegrating relationships (see Juselius 2004, chapter 10).

Table 4
Five Sets of Sequential Hypothesis Tests on Specific Beta Estimates or Beta Estimate Subsets

Tested Restrictions, restriction numbers in each cointegrating vector (CV)	Explanation/Reasons	Test value, parenthetical p-value and test results
Test set 1: β(PRAW) = β(PCHOC) in CV1 plus identifying restrictions in the 3 cointegrating vectors or CVs		
4 in CV1: β(PRAW) = β(PCHOC); β(PNOCHOC) = β (PSOFT) = β(PBAKERY) = 0	Near-equal coefficients; identifying zero restrictions.	Chi-squared test value = 4.12 (0.128). Evidence was insufficient to reject the tested restrictions since the p-value exceeded 0.05.
2 in CV2: β(QSUGAR) = β(PRAW) = 0	Identifying zero restrictions.	
2 in CV3: β(QSUGAR) = β(PCHOC) = 0	Identifying zero restrictions.	
Test set 2: β(QSUGAR) = – β(PRAW) plus identifying restrictions in the 3 CVs.		
3 in CV1: β (PNOCHOC) = β (PSOFT) = β(PBAKERY) = 0	Identifying zero restrictions.	Chi-squared test value = 3.86 (0.049). The p-value of 0.049 suggests that evidence at the 5 percent level was sufficient to reject the tested restrictions.
2 in CV2: β(QSUGAR) = – β(PRAW);	Nearly proportional, negatively related coefficients;	
β(DS9907) = 0;	Shift dummy for sugar market perhaps not significant and/or relevant to chocolate-based confectionary price, PCHOC;	
2 in CV3: β(QSUGAR) = β(PRAW) = 0	Identifying zero restrictions	
Test set 3: β(DS0212) = 0 in CV1 plus the accepted restrictions above on 3 CVs in test set 1.		
5 in CV1: β(DS0212) = 0; β(PRAW) = β(PCHOC) = 0; β (PNOCHOC) = β(PSOFT) = β(PBAKERY) = 0;	Insignificant t-value (-1.3) in set 1; Previously accepted from test set 1; Previously accepted identifying restrictions from test set 1.	Chi-squared test value of 4.42 (0.219). Evidence was insufficient to reject the tested restrictions since the p-value exceeded 0.05.
2 in CV2: β(QSUGAR) = β(PRAW) = 0;	Previously accepted identifying restrictions.	
2 in CV3: β(QSUGAR) = β(PCHOC) = 0;	Previously accepted identifying restrictions.	
Test set 4: β(DS9907) = 0 in CV2 plus accepted restrictions accepted in test sets 1 and 3 in all 3 CVs.		
5 in CV1: β(DS0212) = 0; β(PRAW) = β(PCHOC) = 0; β (PNOCHOC) = β(PSOFT) = β(PBAKERY) = 0;	Previously accepted restrictions accepted in test sets 1 and 3.	Chi-squared value of 4.4 (0.35). Evidence was insufficient to reject the tested restrictions as the p-vale exceeded 0.05.
3 in CV2: β(DS9907) = 0; β(QSUGAR) = β(PRAW) = 0;	Insignificant t-value (-0.02) in test set 2; Previously accepted identifying restrictions;	
2 in CV3: β(QSUGAR) = β(PCHOC) = 0;	Previously accepted identifying restrictions.	
Test set 5: β(DS0101) = 0 in CV3 with all of test set 4's retained restrictions.		
5 in CV1: β(DS0212) = 0; β(PRAW) = β(PCHOC) = 0; β (PNOCHOC) = β(PSOFT) = β(PBAKERY) = 0;	Previously accepted restrictions from test sets 1, 2, and 3.	Chi-aquared value of 4.4 (0.489). Evidence was insufficient to reject the tested restrictions as the p-vale exceeded 0.05.
3 in CV2: β(DS9907) = 0; β(QSUGAR) = β(PRAW) = 0;	Previously accepted restrictions from test sets 1, 2, 3, and 4.	
3 in CV3: β(DS0101) = 0;	Insignificant t-value (-0.7) on β(DS0101) in test set 4.	
β(QSUGAR) = β(PCHOC) = 0	Previously accepted identifying restrictions.	

Hypothesis Tests on the Adjustment Speed Coefficients

A primary hypothesis test on the estimated adjustment speed coefficients is if each of the variables is weakly exogenous. In effect, the test for weak exogeneity tests whether a variable influences the others in the error-correction process without itself being influenced by (i.e., without adjusting to) the process. The hypothesis is equivalent to testing if the particular variable's (here r=3) adjustment speed coefficients are all zero (Juselius 2004, pp. 231-232). In equation 12 , and given that r=3 and p=6: α is a 6 x 3 matrix of alphas with a row of zeros for the variable being tested for weak exogeneity; A is a 6 x 5 design matrix (with 5 being the number of nonzero and unrestricted alphas in each of the three columns of alphas); and ψ is a 5 x 3 matrix of nonzero alphas (see Juselius 2004, pp. 231-231). Basically, the ψ is the alpha matrix without the α's that are being tested as zero. The test value in equation 11 is distributed as a chi-square distribution with 3 degrees of freedom (three single alpha coefficients being zero-restricted). Evidence in all six cases was sufficient to reject the null hypothesis of weak exogeneity.[29]

Economic Analysis of the Three Cointegrating Relationships for U.S. Sugar-Related Markets

We attempt to economically interpret the identified and fully restricted set of cointegrating relationships in equations 14, 15, and 16, which are followed by the adjustment speed (or α) coefficients. Parenthetical values below the β- and α-coefficients are t-values (Johansen and Juselius 1990, 1992).

$$(14)\ QSUGAR = \underset{(-24.12)}{-5.02}*PRAW - \underset{(-24.12)}{5.02}*PCHOC - \underset{(-8.2)}{0.91}*DS9907 + \underset{(4.4)}{0.50}*DS0101 + \underset{(9.6)}{0.014}*TREND$$

$$(15)\ PCHOC = \underset{(7.36)}{20.32}*PNOCHOC + \underset{(4.32)}{7.47}*PSOFT - \underset{(-6.2)}{12.28}*PBAKERY - \underset{(-7.5)}{0.66}*DS0212 + \underset{(4.0)}{0.30}*DS0101 - \underset{(-2.68)}{0.014}*TREND$$

$$(16)\ PRAW = \underset{(-6.12)}{-4.53}*PNOCHOC \underset{(-1.92)}{-0.92}*PSOFT + \underset{(4.9)}{2.66}*PBAKERY \underset{(-10.7)}{-0.16}*DS9907 + \underset{(6.86)}{0.16}*DS0212 + \underset{(2.33)}{0.003}*TREND$$

	Alpha1	Alpha2	Alpha3
ΔQSUGAR	-0.1069	0.1398	0.4831
	(-3.7630)	(3.0133)	(2.9391)
ΔPRAW	0.0027	-0.0404	-0.2582
	(0.1713)	(-1.5769)	(-2.8466)
ΔPCHOC	-0.0721	0.0996	0.3603
	(-6.4254)	(5.4320)	(5.5463)
ΔPNOCHOC	-0.0043	0.0118	0.0311
	(-1.4341)	(2.4076)	(1.7866)
ΔPSOFT	-0.0165	0.0275	0.0921
	(-3.6132)	(3.6981)	(3.4913)
ΔPBAKERY	-0.0031	-0.0009	0.0229
	(-1.0997)	(-0.1998)	(1.4164)

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[29] The weak exogeneity test values and (parenthetical) p-values were as follows: 14.7 (0.002) for QSUGAR; 22.2 (0.000) for PRAW, 28.6 (0.000) for PCHOC; 9.0 (0.03) for PNOCHOC, 11.2 (0.01) for PSOFT, and 12.6 (0.005) for PBAKERY. Evidence was sufficient to reject the null hypothesis of a variable's zero-valued α-coefficients when the test value p-values fell below 0.05 (coinciding with the 5 percent significance level).

Cointegrating relation 1: An economy-wide demand for sugar as an input

Equation 14 appears to be a U.S. economy-wide demand equation for raw sugar as an input. This is because own-price or PRAW has a negative and statistically significant β-coefficient. As well, having normalized on sugar quantity conceptually places it in positive form "above the equilibrium" on the relation's left side, whereby the adjustment coefficient corresponding to QSUGAR in the first relation is negative (-0.1069), statistically significant, and suggestive of a demand's downward adjustment towards long run equilibrium (following Juselius 2004, also known throughout as "the attractor set").

As well, statistical evidence on the first relation strongly suggests an equality of β-coefficients on PCHOC and PRAW, which generated strongly significant t-values of -24. This may suggest some sort of a proxy or "co-price" role for PCHOC as QSUGAR demand's own-price.

Given that all data were modelled in natural logarithms, we follow Juselius' (2004, chapter 10) characterization and interpret the cointegrating β-coefficients as long run elasticities in equations 14 through 16. In equation 14, this would imply that the own-price elasticity of raw sugar demand is -5.02.

At first glance, this may seem a rather elastic estimate for a raw farm commodity. However, the modelled QSUGAR series has a standard error of 26 percent, compared with a far less 9.9 percent for PCHOC, the own price proxy, and an even smaller 5.9 percent for PRAW.[30] Perhaps PRAW's role as a market-clearing force has been interfered with by the exogenous U.S. sugar policy changes and price support efforts (through the loan rate mechanism) which may have stymied its ability to vary in way that clears the market. These policy-induced and offsetting PRAW effects stymied PRAW's ability to respond over time (note, small standard error) and may have detracted from PRAW's role as an effective own-price for QSUGAR.

As well, QSUGAR clearly behaves with a far higher degree of volatility than PCHOC, an industrial wholesale price for a multi-product set of U.S. manufactured and chocolate-based confectionary products,[31] as multi-product price aggregates likely fluctuate with less relative volatility than the "mono-commodity" QSUGAR variable. On average historically, the -5.02 beta estimates suggest that QSUGAR moves with a relatively far more pronounced level of volatility than the policy-constrained PRAW and the mildly fluctuating multi-product PCHOC. In any case, equation 14's-5.02 elasticity on PRAW and PCHOC suggest that QSUGAR seems very sensitive to changes in prices of sugar-containing products. Future research should focus on finding or developing a more relevant and precisely defined own-price proxy for raw sugar, and illuminate evidence on if the elasticity is indeed so elastic, or arises because of the statistical degrees of variability of QSUGAR relative to those of PRAW and PCHOC.

The first relation's α-related results ("alpha1" above) reinforce that equation 14 or the first cointegrating relationship is a demand for sugar as an input with an own-price role "delegated" jointly to PRAW and PCHOC. While previous tests rejected the null hypothesis that PRAW was weakly exogenous to the system, equation 14's α(PRAW) has a near-zero value and is statistically insignificant (t-value of

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[30] Recall that data levels are in natural logarithms rendering the standard error values as proportional changes, which are translated into percentage changes when multiplied by 100.

[31] According to U.S. Department of Labor staff, PCHOC (as herein defined) is an industry price aggregate price incorporating products for the entire U.S. chocolate-based confectionary products subsector. And while Department of Labor staff would not divulge sampling information, the analyst said that PCHOC used in this study was aggregated across scores, perhaps at least 50, separate product prices. Such an aggregate of at least 50 products likely cannot fluctuate as freely as mono-commodity variables such as QSUGAR. Author's telephone communication with staff, U.S. Department of Labor, Bureau of Labor Statistics, Producer Price Division, Jan. 28, 2005.

0.17), whereas β(PRAW) is negative and statistically significant. This suggests that PRAW enters into, but is not markedly influenced by the error correction process in equation 14. This “nearly weakly exogenous” role of PRAW in equation 14 may be caused by the variable’s susceptibility to be influenced by exogenous U.S. sugar policy shocks previously discussed [and captured by equation’s β(DS9907) which is highly significant]. Further, as “co-own-price,” PCHOC has produced a negative and strongly significant α(PCHOC) [t-value of -6.7 in alpha1 above], suggesting that a disequilibrium position of the equation above the long run equilibrium or attractor set would be met by a demand-consistent decline in both QSUGAR and in PCHOC, given the negative and significant α values on these two variables in equation 14 (the first cointegrating demand relation).

The “co-price” relationship between chocolate-based confectionary price and own-price may be further supported by the relative statistical results for the β’s on the deterministic components in equation 14. The four policy changes captured by DS9907 have significantly, and on balance negatively, influenced QSUGAR demand during the 1999:07-2004:03 subsample.[32] The 2001-2002 increases in confectionary input costs captured by the positive and significant β(DS0101) may have led to substituting shifts from non-sugar to sugar inputs so as to have raised QSUGAR demand and have linked QSUGAR demand to the confectionary market events (including those which influence PCHOC) during the 2001:01-2004:03 subsample. Finally, despite the offsetting QSUGAR effects in latter sample subperiods suggested by β(DS9907) and β(DS0101), the β(TREND) is significant, positive (although moderately valued) through the entire sample. This suggests that the positive influences captured by the sugar-using market through DS0101 relevant to the confectionary markets and PCHOC overwhelmed the negative policy-induced effects captured by DS9901 relevant to the sugar market and PRAW. These results suggest that both the sugar and sugar-using markets influence sugar demand, but have led, on balance, to a modest positive QSUGAR trend over time.

Cointegrating relation 2: A possible price transmission among sugar-based products

The second cointegrating relationship in equation 5 seems to be a long run relationship among sugar-based product prices. Similar commodity-related price transmissions such as those of Bessler, Yang, and Wongcharupon (2003) uncovered for wheat-related prices are increasingly common in time series research. The prices between chocolate-based confectionary, non-chocolate confectionary, and soft drinks is a positive one, with the three t-values being strongly significant. Coefficients on PBAKERY in this and the third relation suggest opposing patterns of influence and are discussed below separately. There may be two explanations for this positive relationship of the normalized PCHOC variable with PSOFT and with PNOCHOC: (i) common driving forces from consumer-based substitutability among the three product groups, and (ii) common supply-side production cost forces from a shared dependence on sugar as a major production input and cost.

In the first explanation based on demand substitutability, a rise in consumer demand for soft drinks or for non-chocolate confectionary products may induce a rise in PCHOC on the left hand side of equation 15 as consumers shift demand from soft drinks and non-chocolate confectionary products towards a sugar-based alternative, chocolate-based confectionary products. The second cointegrating relation may also arise from common patterns of sugar-based production costs. PCHOC shares a production cost dependence on sugar with PSOFT and PNOCHOC. Should sugar prices fall (or rise), production costs of the confectionary and soft drink industries would fall (or rise). In this case, a

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[32] Recall that the four policy changes had different and opposing effects on QSUGAR and PRAW. This results suggests a net negative effect of the four policies on sugar demand in relation 1.

"falling/rising tide" of sugar-based production costs would induce a rise/fall in these three prices in the second cointegrating relation.

The α-coefficients for the second cointegrating relation ("alpha2" above) appear consistent with the β-related results in equation 15 above. The second cointegrating relation's three coefficients – α(PCHOC), α(PNOCHOC), and α(SOFT) – are statistically significant and positive, suggesting that should the second cointegration relation be above (below) the long run equilibrium or attractor set, all three prices would rise (fall) towards equilibrium. The speeds of such error-correction towards the attractor set would be in the following ordering in line with parenthetical α-values, with PCHOC leading the group: PCHOC (0.10), PSOFT (0.028), and PNOCHOC (0.012).

Given β(DS0101)'s strong statistical significance in equation 15 (t-value of 4.0), the 2001-2002 confectionary input cost increases that the dummy variable was designed to capture appear to have increased PCHOC over time.[33] Over the entire sample, TREND appears to have had a significant, positive, though mild, effect on relation 2.

Cointegrating relation 3: A production cost link among sugar and sugar-using prices

The third cointegrating relationship appears to negatively relate raw sugar price to non-chocolate confectionary and soft drink prices. Transmissions among a commodity price and downstream prices for products using the commodity have been common in recent time-series research.[34] A possible explanation may be a common input demand relationship with sugar as a productive input. Should the price of soft drinks or non-chocolate confectionary rise (fall), consumers may demand less (more) of such products, leading to a drop (rise) in production, a drop(rise) in the use of sugar as an input, and hence a fall (rise) in PRAW.

The adjustment speed coefficients in the "alpha3" column above appear to reinforce such a relationship. This is because equation 16's α(PRAW) is a significant and negative (t-value of -2.85), whereas α(PSOFT) is significant and positive and α(PNOCHOC) is positive and marginally significant (significant at the 10 percent level). These relation-3 alphas are consistent with a pattern of adjustment speed coefficients which, were the relationship above equilibrium, error correction would occur with a fall in PRAW and a rise in the other two prices. With equation 16's α(PSOFT) of 0.09 being 3-4 times the absolute values of PNOCHOC (0.03) and PCHOC (0.02), it appears that PSOFT adjusts to a random shock from the long run equilibrium substantially faster than PCHOC. This faster response may arise from an ability of the soft drink industry to substitute between high fructose corn syrup and sugar for some of the multi-product price's products.

Consistent with figure 2, the four U.S. policy changes seem to have negatively influenced PRAW in equation 16, insofar as β(DS9907) is negative and very significant (t-value of nearly -11.0). Perhaps

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[33] The negative and significant beta on the shift dummy DS0212, restricted into the cointegration space to account for the late-2002 run-up in prices of U.S. non-chocolate confectionary products is not easily explained. However, DS0212 and DS0101 do overlap: DS0101 was designed to capture both the early 2001 rise in cocoa prices and the late-2002 rise in other confectionary input prices, while DS0212 was designed to capture only the latter late-2002 event to service the non-cocoa confectionary price, PNOCHOC. Collinearity between DS0101 and DS0212 may account for β(DS0212)'s unexpectedly negative sign in cointegrating relation 2 or equation 15.

[34] See Goodwin, McKenzie, and Djunaidi (2003) for transmissions among U.S. price of chicken products, and Babula, Bessler, and Payne (2004) for transmissions among U.S. prices of wheat and various wheat-related value added products. As well, see Babula and Rich (2001) for transmissions among U.S. prices of durum wheat, semolina, and pasta.

the two years of payment-in-kind sugar policy benefits placed enough raw sugar on the market to have a net, declining effect on PRAW. Likewise, the late-2002 rise in non-cocoa confectionary input prices seems to have caused a switch towards sugar as a substitute input, insofar as equation 16's β(DS0212) is positive and significant (t-value of 6.9). Interestingly, over the entire sample (and not just for the 1999:07 – 2004:03 subsample pertinent to the three shift dummy variables), trend has been positive and significant, although the beta value is very modest and near-zero.

Comments on the two price transmissions generally, and on bakery good price's role

The price of bakery products, PBAKERY, appears to engage in the error correction process in equations 15 and 16 in a unique manner from other prices on the right-hand side of the equation. Equation 15 posits a positive relationship among PCHOC, PNOCHOC, and PSOFT, while PBAKERY is negatively related to these three other prices, which could suggest complementarity among demands for bakery products and the three other product groups. Equation 16 posits a negative relationship among PRAW and the two sugar-using prices of PNOCHOC and PSOFT, while the PRAW relationship with PBAKERY is a positive one. The positive PRAW-PBAKERY relationship may arise from a positive correlation among bakery product costs and raw sugar prices.

Although previous tests on weak exogeneity suggest that evidence was sufficient to reject the null hypothesis that PBAKERY was weakly exogenous to the system, the β(BAKERY) and α(PBAKERY) coefficients in equations 15 and 16 suggest that PBAKERY may be nearly weakly exogenous. The β(BAKERY) coefficients in the second and third relationships are strongly significant and suggest that bakery price does influence both relationships, although the adjustment speed coefficients in the latter two of the three cointegrating relationships are insignificant. Because system-wide tests suggested no weak exogeneity, we did not impose weak exogeneity on PBAKERY and did not estimate a conditional cointegrated VEC as recommended by Juselius (2004, chapter 11). Nonetheless, the PBAKERY β and α results in the second and third relationships suggest that PBAKERY influences the error correction process substantially without itself responding with any notable strength to the process. Perhaps PBAKERY is some sort of an informational variable of market conditions that is well-watched by the confectionary, soft drink, and sugar growing subsectors or industries. Recent research has uncovered evidence that fails to reject such hypotheses for bread price serving as a widely watched information or strategy variable for the U.S. wheat-based milling and markets for other wheat-based products.[35]

Clearly, there are limitations to these results which are left for future research. We attempted to have the VEC model include all relevant information for which data were available. It is well-known that beta estimates in a fully restricted cointegrated VEC are sensitive to the completeness of the included information set. Perhaps the "own price" elasticity of QSUGAR demand of -5.0 is high because monthly quantity variables for the sugar-based confectionary, bakery, and soft drink prices are just not available. Future research efforts should be focused on obtaining a more adequate monthly data sets with which to model U.S. sugar and sugar-based markets. Should such data resources surface, perhaps more light could be shed on the nature of PBAKERY's "nearly weakly exogenous" role in the error correction mechanism, and why PBAKERY's participation differs from the other price relationships in the latter two cointegrating price transmissions (equations 15 and 16). The primary goal here is to provide an analytical road map for the first time in applying the methods of the cointegrated VAR model to U.S. sugar-related product markets for the, and to provide the first estimates of cointegrated relationships.

Another important point is that the beta and alpha estimates are greatly influenced by the four policy changes captured by DS9907, and the events in the confectionary markets captured by DS0101 and

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[35] See Babula, Bessler, and Payne (2004, pp. 18-19).

DS0212. All three of these permanent shift dummy variables were restricted to the cointegration space and often generated highly significant β- and α-coefficients. Juselius[36] cautioned that the β- and α-coefficients in equations 14-16 would likely be sensitive to and vary with such new U.S. policy changes as those from the upcoming new U.S. farm bill and/or from other influential events in the other modelled sugar-based markets downstream.

Summary and Conclusions

There is currently great interest in valid and reliable estimates of demand and supply elasticities that drive U.S. markets for sugar and sugar-based products, as well as in evidence on how such markets dynamically interact. The United States has either recently concluded or started negotiations for free trade agreements with a number of noted sugar exporter countries that would like to increase access into the U.S. sugar import market. As a result, policy makers, sugar producers and users, industry agents, negotiators, and researchers have a need for accurate empirical estimates of crucial price elasticities and price transmissions that drive these sugar-related markets and govern the interactions among such markets.

As well, there has been an explosion in the number of applications of cointegrated VAR and VEC methods of Johansen (1988), Johansen and Juselius (1990, 1992), and Juselius (2004) to agricultural economics, and many were cited herein. Despite this increasing interest in market relationships among U.S. markets for sugar upstream and sugar-using value-added products downstream and in applying Johansen-Juselius cointegrated VEC modelling methods, this may be the first empirical application of these methods on these U.S. markets for sugar, confectionary, soft drink, and bakery products.

A survey of data resources located a monthly 1992:01-2004:03 sample of six U.S. sugar-based variables: the U.S. market-clearing price and quantity of raw sugar, the price of chocolate-based confectionary products, the price of non-chocolate confectionary products, the price of soft drinks, and the price of commercial bakery products. A VAR and ultimately a cointegrated VEC of the above six variables were specified and estimated.

Following Juselius (2004), we focused intensely on the data's behavioral issues which preclude conditions of weak stationarity and ergodicity required for valid time series econometric regressions (Granger and Newbold 1986). Such issues to be addressed in specification included: a failure for levels to frequently cycle and mean-revert; non-constancy of means and variances; seasonal effects; market effects of U.S. sugar policy changes; influential confectionary market events; and recurrent non-normal effects of influential outlier events. Substantial effort was then placed into formulating and estimating a well-specified unrestricted VAR model, and its equivalent, an unrestricted VEC using a battery of dummy variable specifications and diagnostic test values. A series of sequential estimations of the six-variable unrestricted VAR and VEC were done in order to modify and enhance specification by capturing influences of events rendering the data's behavior non-normal, and to render an unrestricted VEC with residuals which behaved with approximate statistical normality. Tools and tests included variously specified permanent shift dummy variables to capture pronounced influences of institutional/policy changes and extraordinary market effects, transitory "blip" dummy variables to capture the statistically non-normal influences of outlier events; goodness of fit indicators; Doornik-Hansen normality tests, ARCH effect tests, and values for skewness and kurtosis (among others). Although a first examination of the data and its formidable elements of statistically non-normal behavior may have discouraged some

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[36] These points were made by Dr. Katarina Juselius in two private communications with the author concerning the cointegration space estimates in equations 14, 15, and 15: communications sent to the author on Sept. 14 and 21, 2004.

researchers from further modelling efforts, the benefits of the specification efforts suggested by Juselius (2004, chapters 4, 5, and 6) are clearly evident, when one peruses table 1 and when one compares the plotted data with the plotted three cointegrating relationships ultimately gleaned from the finally restricted cointegrated VEC model.

Evidence suggested that the vector of six sugar-based series indeed constituted a cointegrated system bound by three cointegrating relationships, such that the rank of the cointegration space was r=3. Following Johansen and Juselius (1990, 1992) and Juselius (2004, chapters 10, 11, 12), a series of hypothesis tests on the β- and α-coefficients was implemented to statistically identify the system by meeting the rank condition of identification, and then to economically identify the system of three relationships for meaningful and policy-relevant interpretation. Each tested restriction which was accepted by the hypothesis test procedures on the β- and α-coefficients was retained and the system re-estimated with the last imposed restrictions using the reduced rank estimator of Johansen (1988) and Johansen and Juselius (1990, 1992). Ultimately, a three-relation cointegration space emerged. One relationship appears to be a U.S demand relation for sugar as a production input. The second and third appear to be long run price relationships. The statistical strength of these three relationships was strong.

In the first relation (sugar demand), QSUGAR appears tied to a linear combination of the highly regulated raw sugar price and the chocolate-based confectionary price. One surprise was evidence that own-price or PRAW may not be an effective one: countervailing PRAW effects of U.S. sugar policy changes have likely stymied its ability to respond to sugar market forces, as seen particularly by the very significant coefficient on the DS9907 dummy variable. Evidence suggested that the influences of sugar containing product prices (PCHOC) was equal to that of PRAW or own price, to render some sort of a "co-own-price" role shared by the two on sugar demand. Strictly speaking, own-price elasticity of sugar demand as in input appeared rather elastic (-5.0), although this may be explained by the relatively mild fluctuation levels of the own-price "cooperators" relative to QSUGAR's degree of variability over time. Future research, preferably when other sources of data are collected or uncovered, may generate a more meaningful price elasticity of sugar demand.

The second cointegrating relationship ties together PCHOC, PNOCHOC, and PSOFT into a price transmission relationship. These three prices move positively through time. Binding forces may be based on substitutability of consumer demand for these three sugar-using products and/or perhaps on a common dependence on sugar as a major production input.

The third cointegrating relationship relates the raw sugar price negatively to PNOCHOC and PSOFT. This relationship may be based on PRAW's influence on PNOCHOC and PSOFT through production costs.

Other results suggest that PBAKERY is at most a marginally endogenous participant in the second and third cointegrating relationships and may well serve some as a sort of a signal of market conditions or information variable. As well, trend appeared important, probably because of the PRAW-decreasing U.S. sugar policy changes which in turn influenced other modelled variables (figure 2).

The first demand-like cointegrating relationship was more easily defined or economically identifiable than the second and third cointegrating relationships which tied various sugar-based prices into two long run price transmission mechanisms. Interpretation of these second two is preliminary, perhaps because of a less-than-adequate information set or variable set which excludes relevant important variables which our survey just failed to locate or which have been yet to be made publically available. Insofar as no other relevant monthly data resources were located, resolution of a more exact interpretation of these price transmission mechanisms constituting the second and third cointegrating relationships is relegated to future research.

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